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RESEARCH MEMORANDUM

SPINNING AND RELATED PROBLEMS AT HIGH ANGLES OF ATTACK FOR HIGH-SPEED AIRPLANES

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SUMMARY

A discussion is presented of the type of control manipulation and various techniques that may be required for satisfactory spin recovery of contemporary fighter designs. The effects in spins of jet-engine installations and the effectiveness of canard surfaces in alleviating a directional divergence near the stall and subsequent spin entry on one configuration are also discussed.

INTRODUCTION

The mass characteristics of fighter airplanes have changed in recent years from a mass regime wherein the moments of inertia about the pitch and roll axes were nearly equal to a new regime wherein the moments of inertia about the pitch axis are very large with respect to those about the roll axis. This shift in the mass regime is illustrated in figure 1. Variations in the parameter plotted diagonally, $\frac{I_X - I_Y}{mb^2}$, indicate the relative distribution of mass in the wings and the fuselage of an airplane. Positive values of this parameter indicate that the mass is predominantly in the wings and negative values indicate that the mass is primarily in the fuselage. The two designs shown in the lower right of the figure represent the old type of airplanes whereas those in the upper left are examples of present-day fighters which are generally very heavily loaded along the fuselage. The present paper deals with airplanes of this latter type.

Whereas rudder and elevator reversal were recommended for spin recovery with the older type of airplanes, ailerons with the spin are required for recovery (stick right in a right spin) with the present-day fighters unless the airplane has an unusually effective vertical tail. Generally, ailerons designed to provide the required effectiveness in normal flight have been found to be effective in bringing about spin recovery. Combinations of high inertias and possible high angular velocities in spins, however, and also the practice of moving ailerons inboard on the wing or substituting upper-surface spoilers for them may give rise to situations in which the lateral controls may not be sufficiently effective. As a result it may be necessary to resort to other means for spin recovery, and some possible techniques are presented in this paper. The effects in spins of jet-engine installations and pilot confusion in spins are also discussed.

SYMBOLS

b	wing span, ft
ΔC_l	incremental rolling-moment coefficient
ΔC_n	incremental yawing-moment coefficient
I_X	moment of inertia about X-axis, slug-ft^2
I_Y	moment of inertia about Y-axis, slug-ft^2
I_Z	moment of inertia about Z-axis, slug-ft^2
M	Mach number
m	airplane mass, slugs
$N_{aerodynamic}$	aerodynamic yawing moment, ft-lb
p	rolling angular velocity, radian/sec
q	pitching angular velocity, radian/sec
r	yawing angular velocity, radian/sec
$\dot{r}$	yawing angular acceleration
S_a	total aileron area, sq ft
y	spanwise coordinate from plane of symmetry to centroid of aileron, ft
δ_a	total aileron deflection, radian or deg
V	vertical velocity in spin, ft/sec
α	angle of attack, deg
Ω	angular rotational rate of spin, radian/sec

RESULTS

In order to review briefly the reasons for the effectiveness of ailerons in spins, it appears desirable to examine the yawing-moment equation because experience has indicated that the yawing moment is the most significant moment affecting spin recovery. The following equation for yawing moment does not include product-of-inertia and engine gyroscopic terms:

$$N_{aerodynamic} + \left(I_X - I_Y\right) pq = I_Z \dot{r} \tag{1}$$

As regards aileron effectiveness in spin recovery, provision of an inertia cross-couple yawing moment to oppose the spin rotation has been found to be very effective. In reference to the inertia cross-couple term of equation (1), $\left(I_X - I_Y\right)pq$, it is desirable that the pitching velocity q be positive or nose up to produce a yawing moment opposing the spin for the types of loadings considered $\left(I_Y \text{ in excess of } I_X\right)$. If the inner wing is depressed in a spin, a positive or nose-up pitching velocity will be obtained. Thus, if ailerons displaced with the spin apply a rolling moment sufficient to depress the inner wing below the horizontal in the spin, the pitching velocity will be in the proper sense to provide a yawing moment opposing the spin. The ability of ailerons to apply a rolling moment in the desired direction at spin attitudes is shown in figure 2.

Angle of attack is plotted horizontally and the upper portion of the figure indicates the rolling-moment coefficient provided by the ailerons. Figure 2 indicates that, although the aileron rolling moment drops off as the angle of attack increases, the ailerons are still effective in applying a rolling moment in the desired direction even at very flat spinning attitudes for the envelope of rotational rates presented. The lower portion of the figure presents yawing moment against angle of attack and shows that ailerons with the spin also apply an antispin aerodynamic yawing moment.

In recent model tests, flat rapidly rotating spins have been obtained on some contemporary fighters having the horizontal tail placed low on the fuselage and on some horizontal tailless designs. In such instances provision of even a large rolling moment with the spin may not be an effective recovery device. Figure 3 gives an indication of the rolling moment required for various airplane angular momenta for airplanes of this type based on a statistical study. The parameter ΩI_Z plotted horizontally is indicative of the angular momentum about the airplane

Z-axis and the parameter $S_a y \delta_a$ plotted vertically is an aileron area moment; increasing values of $S_a y \delta_a$ indicate more effective ailerons. The chart indicates that for instances where unduly large rotational rates exist extremely large aileron moments may be required unless some other means is employed to slow down the spin rate and thus enable the ailerons to effectively terminate spins.

In the developed spin the rotational rate is directly related to the aerodynamic nose-down pitching moment for a given spin attitude, and large values of nose-down pitching moment lead to rapid rotational rates. Thus, a means of slowing down the spin rotation and rendering the ailerons more effective is by decreasing the aerodynamic nose-down pitching moment. One manner of accomplishing this, which has been found to have some effectiveness, is by deflecting the horizontal tail upward to a large angle.

Another means of slowing down the spin rotation found to be effective in several instances is by extending small canard surfaces that are normally retracted against the sides of the fuselage. Surfaces about 2 to 4 percent of the wing area have been found to be quite effective when they were extended for recovery in conjunction with movement of the regular controls. A typical view of a model with canards installed and extended is shown in figure 4. In addition to making the canards of sufficient size, it is important that they be placed at a high forward position on the fuselage where there is ample fuselage depth below the canard hinge line. Small aspect ratios also appear desirable. Canards aid in terminating spins because they contribute a nose-up pitching moment which is favorable for reasons previously indicated. The canards also contribute a damping in yaw which has favorable effects.

Another means of providing assistance to lateral controls when they are not sufficiently effective alone in terminating spins of contemporary fighters or when ailerons do not exist on the design is by operating the horizontal tail differentially as ailerons.

In connection with the canard surfaces, results of dynamic model tests of one contemporary fighter design have shown that such surfaces suitably positioned were effective in preventing a directional divergence near the stall. These tests were conducted on the launching apparatus used for incipient spin tests. The model without canard surfaces installed diverged directionally after attaining stalled attitudes because of a loss in directional stability and, in some instances, subsequently entered spins. With suitably placed canard surfaces installed, however, the stalled flights of the model were essentially straight.

The use of jet engines has introduced some important factors in spinning: engine gyroscopic effects, thrust effects, and the possibility of directing the thrust to produce desired moments for spin recovery. Experience in a few instances has shown that applying thrust of about $\frac{1}{2}$ g directed through the center of gravity had no beneficial effect on recovery; in fact, thrust applied in such a manner had a somewhat detrimental effect because of an attendant increase in rotational rate. If the thrust can be applied or directed in such a manner as to give a yawing or rolling moment of sufficient magnitude, however, beneficial effects can be obtained. Experiment has shown that, for one design that spun at moderate attitudes and rates, a yawing or rolling-moment coefficient of 0.02 was sufficient for recovery; whereas for another design that had flat rapidly rotating spins, a yawing-moment coefficient of 0.13 was required.

An important contribution of the jet engine in spins is the gyroscopic moment of the rotating parts of the engine. Although no generalizations can be made on the final effect of the gyroscopic moments, two effects are usually consistent: If engine and airplane rotate in the same sense about their respective axes of rotation (that is, a clockwise rotating engine when viewed from the rear and a right-hand spin), the spin will steepen and the rotational rate will increase; if engine and airplane rotate in opposite senses (as a clockwise rotating engine and a left-hand spin), the converse is true - the spin will flatten and the rotational rate will decrease. The steepening of the spin is not always a beneficial effect, however; nor is the flattening always adverse. Corresponding full-scale engine angular momenta investigated on spin models have been as high as 25,000 slug-ft^2/sec. Results of tests on one model wherein gyroscopic effects of jet-engine rotating parts were simulated are presented in reference 1.

Spins of contemporary fighters are often erratic and oscillatory, and a pilot can become disoriented and place the controls in a manner opposite to that required for recovery. Confusion, however, is more apt to occur in inverted rather than erect spins because, when a pilot is in an inverted spin, the rolling velocity that he experiences is opposite to direction of yawing; thus, a pilot may think he is applying controls to oppose the spin rotation while controls are actually being applied to hold the airplane in the spin. (See ref. 2.) It is suggested that a pilot make use of the turn indicator installed in the airplane to determine the direction of spinning, particularly for inverted spins, to make certain he is applying controls in the proper direction to oppose the spin. It may be pointed out that the Langley Aeronautical Laboratory has a spin-simulator seat mounted on gimbals that is available for aircraft-company test pilots as an aid to orientation in spins.

CONCLUDING REMARKS

It may be said that to effect satisfactory recoveries from spins obtained on contemporary fighters, aileron deflection with the spin will usually be required and in some instances the lateral controls may require the assistance of other controls such as the horizontal tail or canard surfaces. Canard surfaces may also offer a means of alleviating the directional divergence near the stall and thereby prevent subsequent spin entry for some contemporary fighters. The gyroscopic moments produced by a jet engine can have appreciable effects in spins, and proper direction of engine thrust to provide a rolling or yawing moment offers a means of obtaining satisfactory spin recovery. In order to avoid pilot confusion regarding spin direction, use should be made of the turn indicator.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 2, 1955.

REFERENCES

1. Bowman, James S., Jr.: Free-Spinning-Tunnel Investigation of Gyroscopic Effects of Jet-Engine Rotating Parts (or of Rotating Propellers) on Spin and Spin Recovery. NACA TN 3480, 1955.

2. Scher, Stanley H.: Pilot's Loss of Orientation in Inverted Spins. NACA TN 3531, 1955.

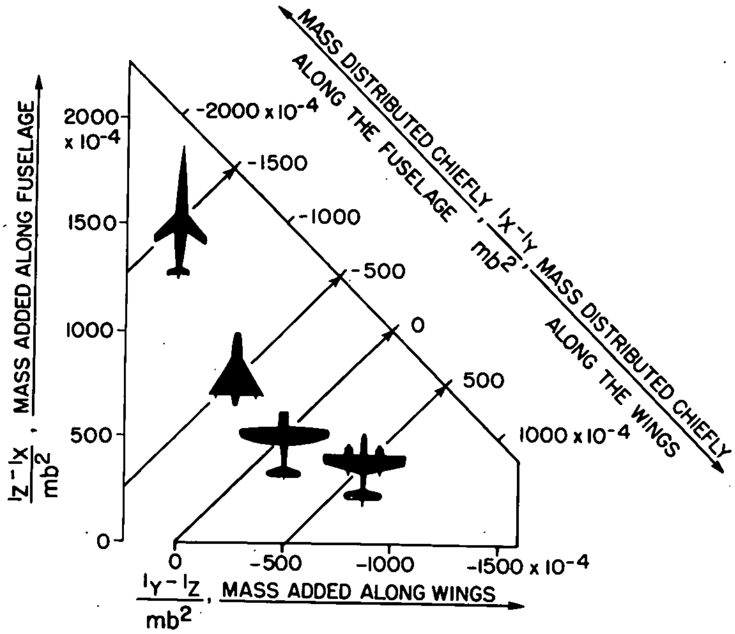

Figure 1

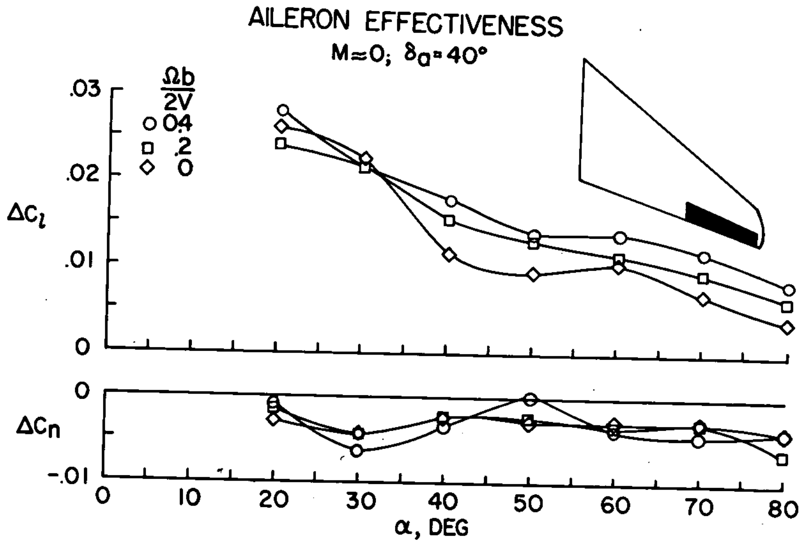

Figure 2

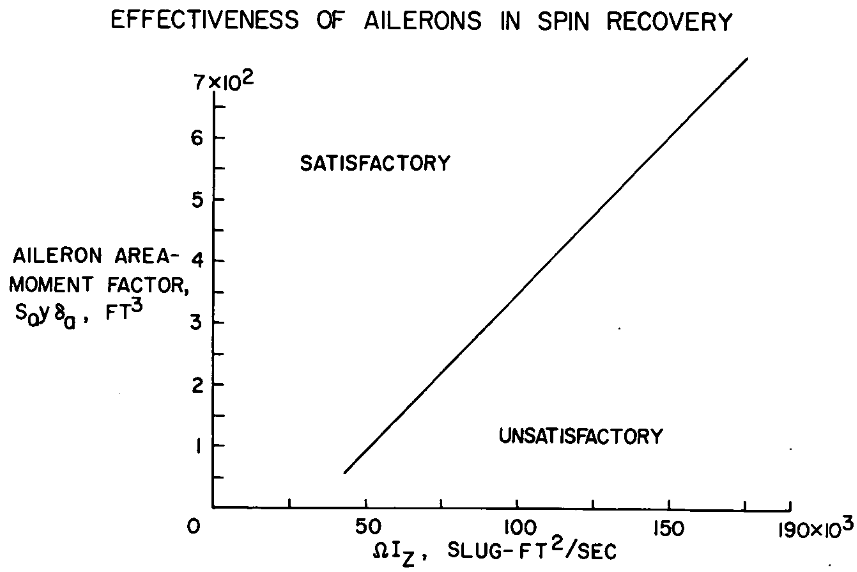

Figure 3

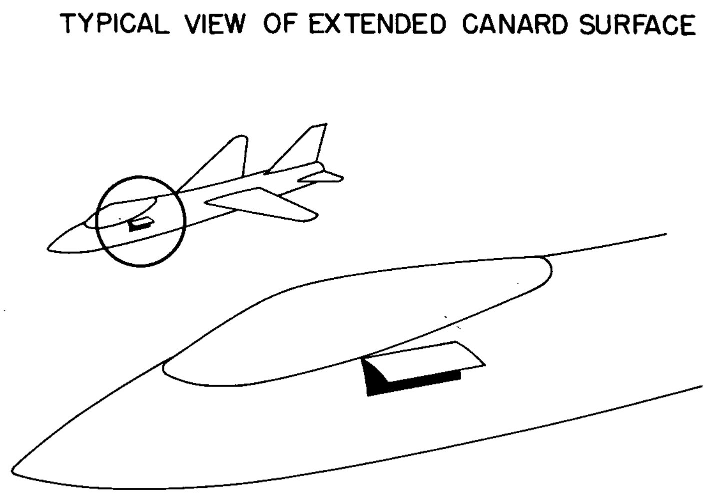

Figure 4